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UNDERWATER NONDESTRUCTIVE TESTING EQUIPMENT AND TECHNIQUES, (U)
1979 F BARRETT, J MITTELMAN

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(6) **UNDERWATER
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(10) by
FRED BARRETT
and
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UNDERWATER NONDESTRUCTIVE TESTING
EQUIPMENT AND TECHNIQUES

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ABSTRACT

Underwater nondestructive testing equipment and techniques were studied at the Naval Coastal Systems Center during FY 78. Aimed at producing hardware for ship hull inspections, this project focused on stereophotography, ultrasonic thickness gaging and flaw detection, and magnetic particle inspections. In each case, hardware was chosen on the basis of an extensive survey of users and manufacturers both in America and Europe. Modification and adaptation of off-the-shelf equipment was performed at NCSC in order to arrive at systems easily used by U.S. Navy divers, and tests were run to determine the performance of each system under laboratory and field conditions. The stereophotography system described is an inexpensive unit which produced photographs of excellent quality in spite of zero visibility conditions. Corrosion pit depths or fouling heights can be measured to approximately $\pm 1/64$ inch, and incipient paint blistering can be detected before the blisters pop. The ultrasonic equipment described provides audible feedback to the diver to assist him in positioning the transducer. Also, thickness readings and flaw signal amplitudes can be stored on computer tape to facilitate later analysis. The magnetic particle inspection systems include permanent record techniques such as magnetic rubber and transferring magnetic particles to a variety of putty-like materials. Techniques for mixing magnetic rubber on site are also discussed, and comparisons are made between various combinations of magnets and magnetic materials.

INTRODUCTION

Underwater inspection is fast becoming a topic of great interest due to pressures brought by financial and regulatory agencies. In maintenance tasks, cost avoidance is perhaps the bottom line that private industry and the Government respond to, and it is in this area precisely that underwater nondestructive testing (NDT) can contribute most effectively. We cover, in this paper, research and development done recently at the Naval Coastal Systems Center (NCSC) in three areas of NDT. This work was sponsored by the Supervisor of Salvage, Naval Sea Systems Command (NAVSEA), SEA OOC. The areas of NDT are magnetic particle inspection, ultrasonic inspection and stereophotography. All three may be carried out without access to the inside of the structure in question and are therefore well suited to ship hull inspections. Further, the three complement each other in that the limitations of one technique are often covered by the strengths of another. This observation will be explained more fully later. The hardware and techniques discussed in this paper are in the development stage and, especially in the area of electrical safety, have not been approved by the Navy.

We, at least in the Navy, live in a world where decisions based on inspection results are generally made by officers who are not witness to the inspection itself and who may have little background in nondestructive testing. Since the weight they accord a diver's subjective impression is understandably minimal, we strive to document as objectively as possible the results of our inspections. To let a structural flaw create its own permanent record is an ideal, and attainable objective in NDT research and development. With this kind of "hardcopy" evidence of a problem in hand, the officer, the decision maker, runs but a small risk of choosing a course of action for which he could be faulted.

In magnetic particle inspections (MPI) our work investigated the basic properties of four magnetic particle materials, four magnetic flux sources and a variety of techniques for making hardcopy records of the MPI results. Perhaps the greatest strength of MPI is its ability to portray, in great detail, the location and length of surface or near surface discontinuities. Even cracks so tiny as to be invisible to the naked eye or close-up camera can be detected and recorded faithfully by MPI. It cannot be used, however, to detect deeply embedded cracks or deep porosity. Also, with some magnetic materials, the inspection process is slow, and some electromagnetic flux sources are not considered safe for use by Navy divers.

Ultrasonic testing (UT) can be used for thickness gaging and flaw detection, even for discontinuities too deeply embedded in the structural material to be detected by magnetic particle inspection. Ultrasonics may be relatively rapid, compared to MPI, but presents far less detail and requires, and in the case of weld inspections, very careful measurements in order to properly interpret UT indications. One result of our work in UT is a thickness scanning system that can be used by divers having virtually no UT skill or experience. For each location gaged, this system outputs the average, standard deviation, maximum and minimum of thickness at this location. This information more accurately portrays the state of corroded steel than a single reading would. Another result of our work in UT is an audible feedback system which allows the diver to find and hold flaw indications while topside personnel evaluate the indication.

Stereophotography is the final area of NDT addressed in this paper. It has many advantages over conventional photography, including the availability of pit depth or fouling height information, and the great assistance to photo interpretation that viewing in three dimensions provides. To take stereo photos we developed an inexpensive clearwater box which results in consistently high quality photographs regardless of turbid water or the diver's skill in photography. Photography complements MPI and UT in that it documents paint and metal surface conditions rather than internal defects.

The NDT hardware, which is the central subject of this paper, can be used as tools for cost avoidance in the maintenance of marine structures. The result of using this hardware is reasonably objective information which can be used to plan in advance the material and labor resources that will be required during an overhaul period. These results can also be used to satisfy insurance or regulatory agency requirements or to forecast the need for structural repairs. In short, these results can be a valuable management tool to the extent that technological progress makes them objective and believable.

MAGNETIC PARTICLE INSPECTION (MPI) - Background

Magnetic particle inspections are particularly well suited for finding and documenting surface cracks on ferromagnetic materials. These cracks are often associated with fatigue and stress induced corrosion. In the Navy, surface ships, submarines, and to a lesser extent, offshore structures may be inspected using MPI techniques. A thorough sounding of the diving companies, inspection services, equipment manufacturers and suppliers in the

United States failed to produce much information on underwater MPI, but European organizations provided a wealth of information related to underwater MPI as practiced in the North Sea. Insurance and regulatory agencies play a major role in assuring the competence of the inspectors and the reliability of the equipment and techniques used. In test plate trials with over 250 divers, the current state-of-the-art will, reportedly, assure a crack detection rate of over 99%. In most cases, the European inspectors use fluorescent magnetic particles and ultraviolet illumination with wavelengths in the 3000 to 4000 angstrom range, but there is a wide variety of electromagnetic flux sources and magnetic particle materials in use.

The electromagnetic flux is commonly produced by permanent magnets, but electromagnets and current prods are also used. Permanent magnets which are used generally provide at least 15 pounds pull, and in one case, a 150-pound pull horseshoe magnet was reported. Current prods, which set up a magnetic field perpendicular to the line between the prods, are typically operated at low voltage (10 volts AC or less) but high current (approximately 1000 amps). The possibility of arcing between the prod and the structure is reduced by using low melting point tips on the prods. No specific information on electromagnets was obtained; however, one company using specially designed electromagnetic heads also documents the flaw indications on electromagnetic recording tape. This tape can later be analyzed electronically to produce an oscilloscope trace showing the flaw location and the flaw signal amplitude or the flaw's size and shape within the weld. This technique, and some of the more conventional techniques using electromagnets or permanent magnets, can be used on painted surfaces.

The choice of magnetic particles seems to differ from company to company, but most companies are successfully using particles in a water (rather than oil) carrier. Particles such as Circle Chemical Companies' Mi-Glow 10, Burmah-Castrol's Castrol Lumor 10S and Magnaflux's Magnaglow 20A are being used. Often the particles are mixed into suspension on the surface, but in at least one case, where they are pressure fed from an underwater container, continuous agitation is provided by a propeller built into the container. In this case, the applicator tip is built into the current prod assembly and the whole inspection system, including hydraulic power, cleaning tools, grinding tools, an electric power transformer, lighting and testing hardware, is mounted in a crane handled submersible cage.

Magnetic particle inspections are generally preceded by a thorough cleaning job, often done with high pressure water jets. These jets have an advantage over wire brushes in that they do not tend to peen metal over the cracks, but rather, make them more visible. After cleaning, a visual inspection is made, and any corrosion pitting, cracking, or other physical damage that can be readily seen is noted. At this point, and at periodic intervals, the proper functioning of the MPI System may be checked using test plates with known cracks. The inspection then proceeds, and if a crack is detected, it may be ground down 2-3 millimeters and rechecked with magnetic particles. Cracks which remain after this procedure are punch marked at each end and later repaired or monitored. A special report form showing the structure and the crack's location supplements the diver's verbal description and, in some cases, a record is made photographically or with television, or by lifting the magnetic particles with a special putty compound.

In the North Sea MPI is used on tubular joints at depths up to several hundred feet with very good results. Where subsequent repairs have necessitated cutting out damaged sections the results of underwater MPI have correlated well with topside inspections of the damaged parts.

MAGNETIC PARTICLE INSPECTIONS - Experimental Work

Based partially on the recommendations of magnetic particle equipment users, and partially on an in-house evaluation of commercially available MPI equipment, four magnetic flux sources, four magnetic particle carrying media and a variety of putty-like compounds were chosen as test items. The intent of the test program was to identify one or more combinations of these components that would allow reliable MPI to be performed underwater. Diver safety was considered at all times, as was ease of inspection. A description of each component used in the tests is presented below.

Contour Probe, Figure 1

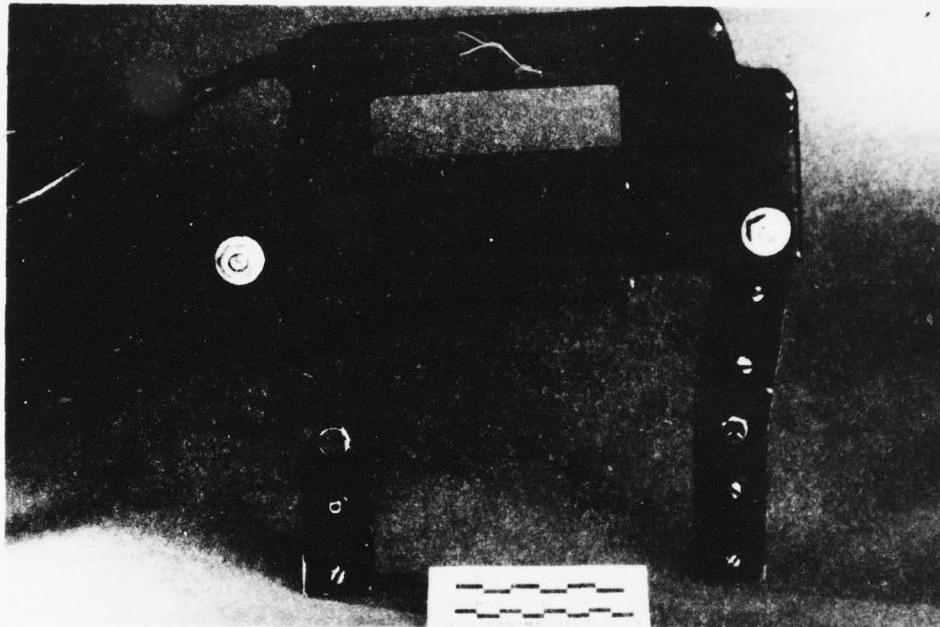


Figure 1. Contour Probe

The probe was fabricated specifically for underwater use by Parker Research Corporation, Dunedin, Florida. It is similar to their contour probe designed for use in air. The primary differences were the elimination of an ON-OFF switch and an AC-DC switch, and addition of waterproof potting of the electrical coil. The switching was eliminated from the handle for reasons of diver safety. A special feature of the probe is the movable arms or pole pieces which make it possible to adjust to different contours, lapped plates or plates or pipes which mate at various angles.

It was considered mandatory for Navy use to use the contour probe in conjunction with a Ground Sentry (to be described in a following subsection). The necessity is based on diver safety requirements.

GENERAL SPECIFICATIONS, Contour Probe

Minimum to maximum distance across poles	0 - 18"
Power requirements	8 amps - 115 VAC
Cable - 2 conductor with braided shield serving as ground conductor.	
Neoprene external cover.	
Weight	13 pounds

Magnetic Inspection Unit, Model WL-1UW, Figure 2.

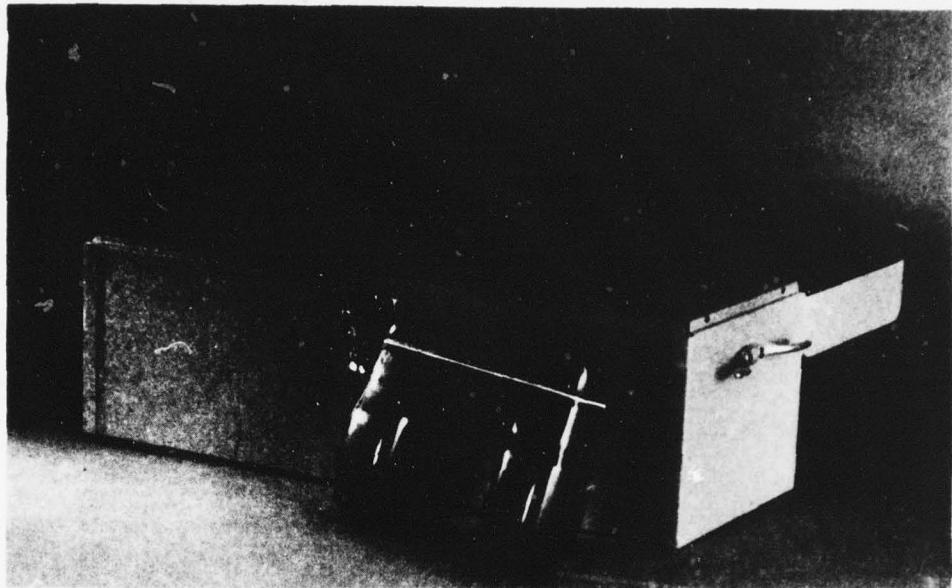


Figure 2. Magnetic Inspection Unit

The unit was fabricated for underwater use by Texas Magnetics, Houston, Texas, and is basically the same as their Model WL-1. The unit is relatively safe for diver use as a 12-volt battery is used for power. Both the use of direct current and low voltage contribute to diver safety. A carrying case is incorporated which contains a circuit breaker, switch and pilot light. The case serves as storage space for 100 feet of cable.

Approximately 40 pounds of lifting force is created by the electromagnet. The unit requires about 3 amps.

The unit weighs $7\frac{1}{2}$ lbs. Pole arms are on a fixed $5\frac{1}{2}$ inch spacing.

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Permanent Magnets, Figure 3

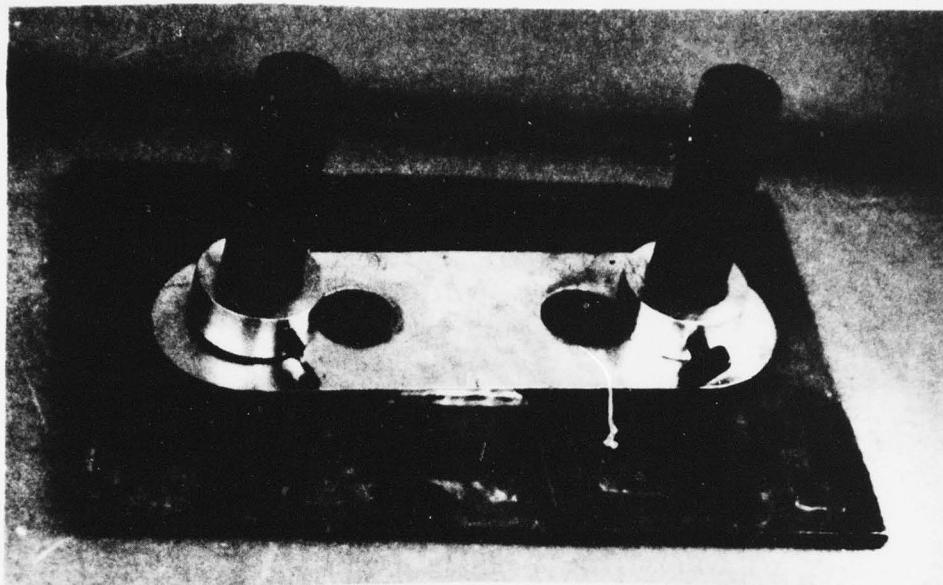


Figure 3. Magnetic Rubber Pouch Held in Place By Plate Assembly

One pair of permanent magnets tested was one inch in diameter and six inches long. These magnets were purchased from Dynamold Inc., Ft. Worth, Texas.

Another pair of 1.55-inch diameter x 6-inch long magnets was obtained from Terry Magnetics, Inc., Orlando, Florida.

Magnetic Particle Supplies

Magnetic Paint #5 - magnetic flakes in an oil base, Magnaflux Corp., Chicago, Illinois.

Magnetic Rubber - Black magnetic particles in a liquid rubber base material, Dynamold Inc., Ft. Worth, Texas.

Magnetic particles in a water base - Mi-Glow 10 and UW-1, Circle Chemical, Inc., Hinckley, Illinois.

Ground Sentry - MK 6, Mod 0, Figure 4.

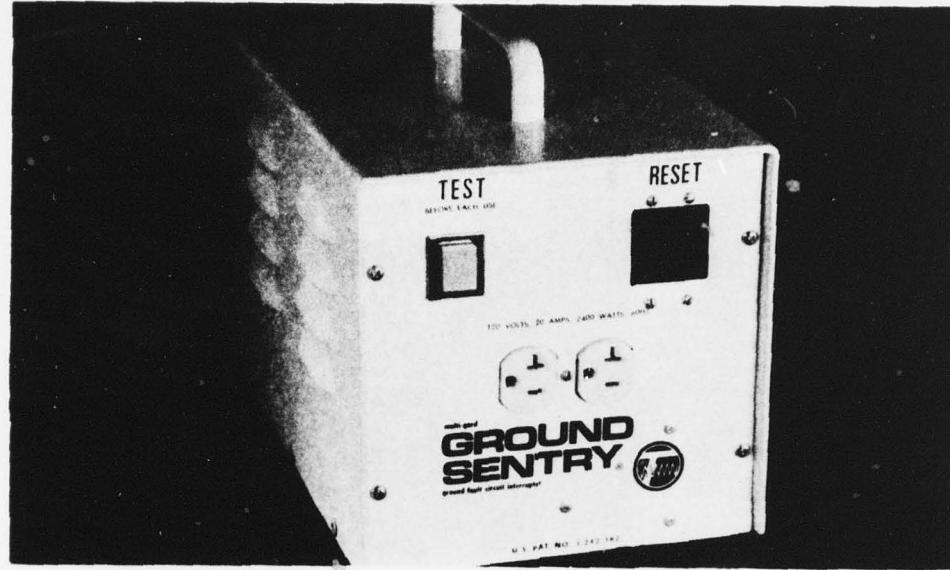


Figure 4. Ground Sentry

The ground sentry incorporates an isolation transformer and a ground fault interrupter. The specifications follow:

Trip current	7 milliamps
Trip time	25 milliseconds
Full load rating	10 amps
Voltage	115 VAC
Frequency	50 - 60 Hz
Circuit breaker rating	10 amps

Manufactured by Trinetics Inc., Mishawaka, Indiana.

Ultraviolet-Mercury Vapor Light, Figures 5 & 6.

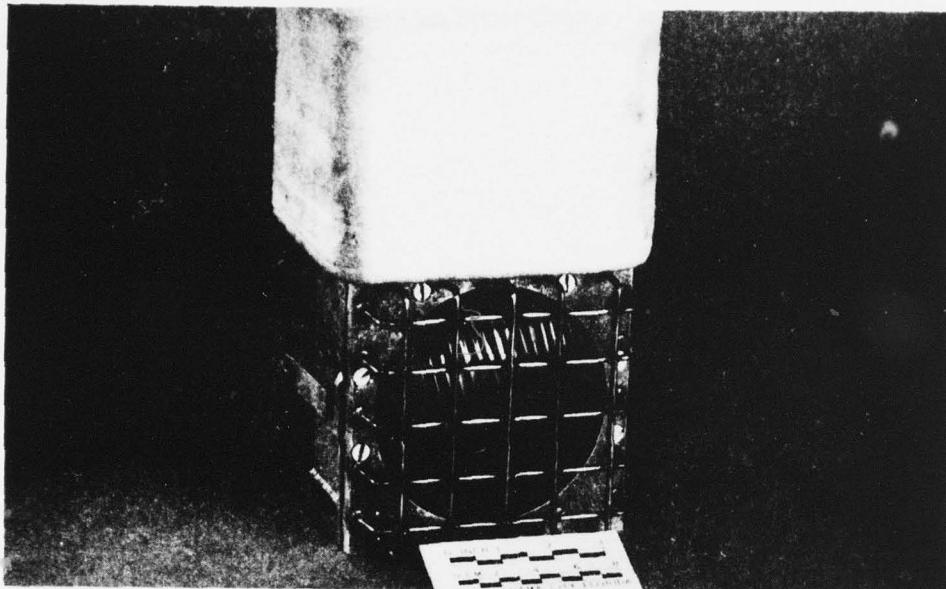


Figure 5. Combination Light Used as Ultraviolet Light

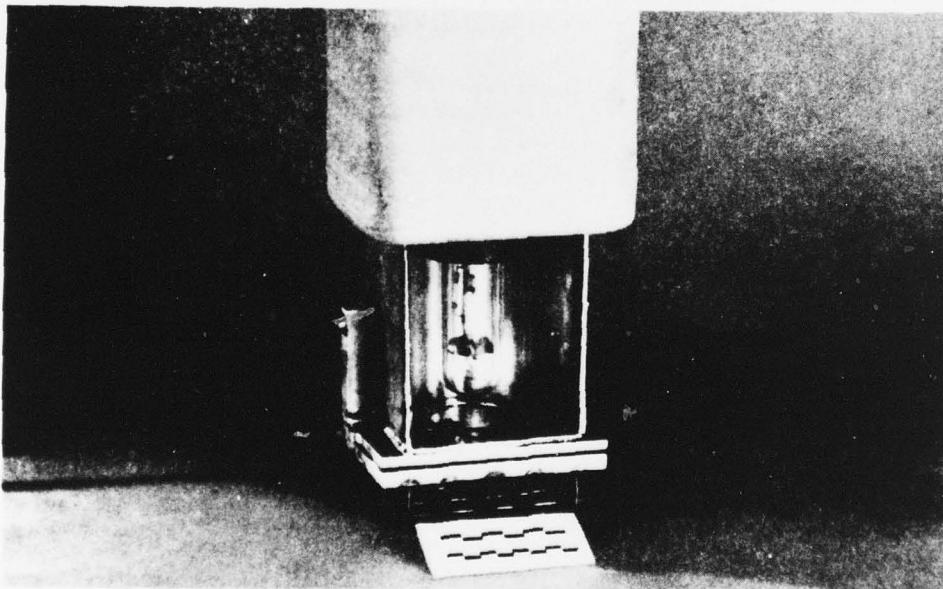


Figure 6. Combination Light Used as Mercury Vapor Light

The light was designed by the author. A mercury vapor light MK 12A manufactured by Sub Sea Systems, Inc., Escondido, California, was used in conjunction with a #3901 Magnaflux Corp. ultraviolet light filter. The special features of the designed light follow:

The filter may be swung underneath the light housing in order to use the assembly as a conventional mercury vapor light for preinspection by divers.

Protection against accidental breakage of the glass filter is provided.
Addition of buoyancy material makes the light neutrally buoyant.

Seal-N-Save Sealer, Figure 7

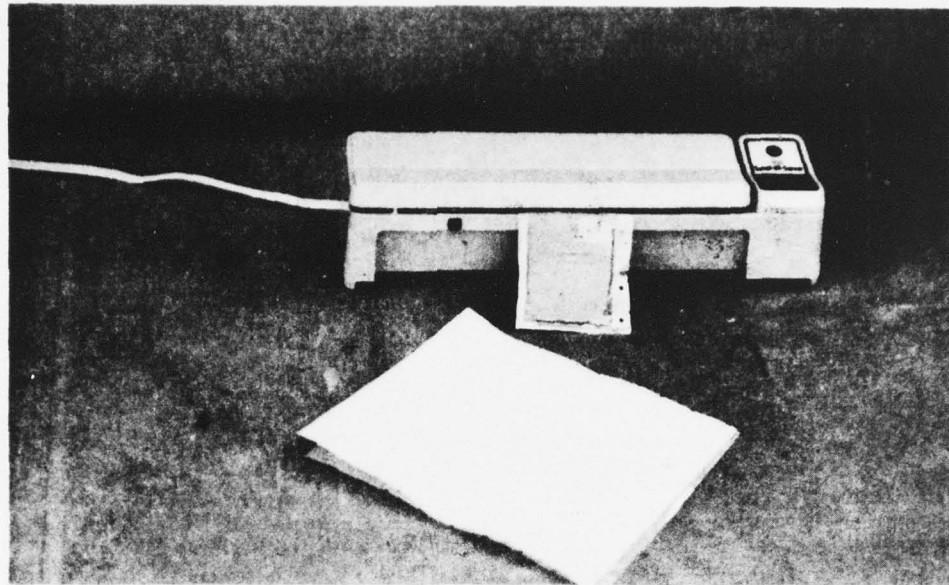


Figure 7. Seal-N-Save Pouch Sealer & Pouches

The sealer and pouch material were used for packaging of the magnetic rubber for diver use. Sears was the supplier.

Test Plates, Figure 8

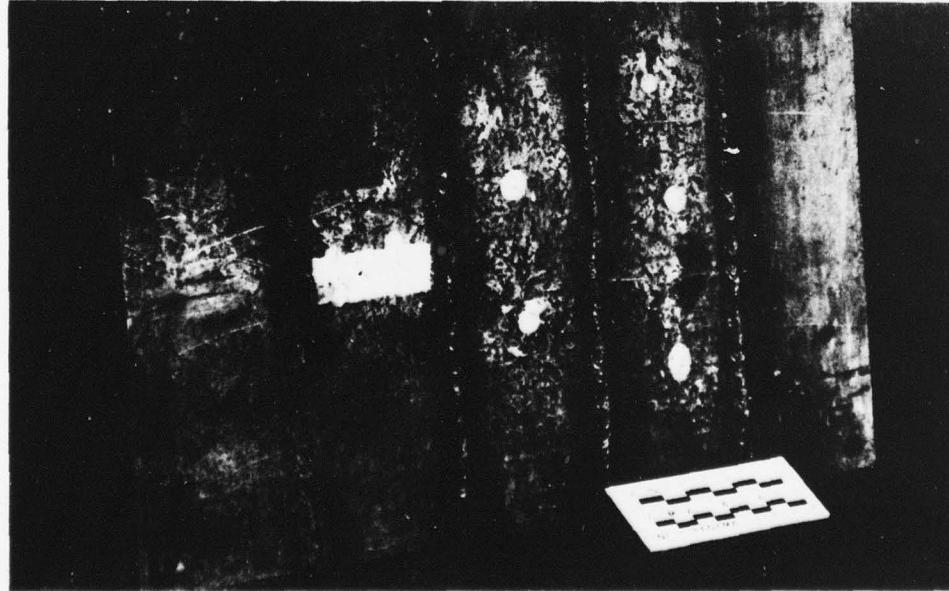


Figure 8. Test Plates

Test plates were made up specifically for the tests. The test plate array was made up of the following separate plates welded together:

<u>Plate</u>	<u>Crack Widths</u>
A (painted with ship bottom paint)	50 to 200 millionths of an inch (μ in.) and 200 to 1000 μ in.
B	50 to 200 μ in.
C	50 to 200 μ in. and 200 to 1000 μ in.
D (cracks on butt weld)	50 to 200 μ in. and 200 to 1000 μ in.
E (milled slots, 1" long x 1/8" deep)	.005 inch, .010 inch and .020 inch

A separate plate was made up with 1/32" x 1" drilled holes located 1/16", 1/8", 3/16" and 1/4" below the surface. All plates were steel, 3" x 10" x 3/8" thick.

TEST METHODS

All tests were conducted in shallow tanks of clear water. Additional tests will be made in murkey harbor water and on ship and submarine hulls and on offshore structure.

Magnetic Rubber. The liquid magnetic rubber was placed in plastic pouches and the required catalyst and conditioner was first placed in gelatin capsules and then the capsule added to the pouch. A Sears Seal-N-Save electrical sealer was used to seal the pouches. The catalyst causes the liquid rubber to solidify.

Pouches were used so that the diver could make up a number of the pouches in advance. When the diver was ready to use the material, he would break the capsule in the pouch and knead the material until it was thoroughly mixed. Electromagnetic force was applied for three minutes where electromagnets were used. The material sets up enough to be removed in about 40 minutes for 70°F water, (a longer time would be required in cold water). When permanent magnets were used, they were left in place until the rubber cured.

Particles are attracted at the site of the crack or drilled hole and form a black line in a light grey background.

An excellent permanent record of detected flaws was formed by the rubber.

The liquid rubber filled pouches were held in place by a stainless steel sheet and collars for the permanent magnets and a piece of .010-inch brass shim stock for the electromagnets.

Magnetic Particle-Water Mixtures

Mi-Glow 10 and a wetting agent were placed in a flexible plastic bottle and the bottle filled with water. UW-1 was used in a similar manner except that no wetting agent was required. In use underwater, the permanent or electromagnet was placed at right angles to the probable longitudinal axis

of the crack, if such was known. The bottle was shaken vigorously to mix the particles and water. The magnetic particles were squirted onto the plate area between the magnets and any excess particle buildup washed away with a waving action of the diver's hand. Sea water replaced the mixture squirted from the bottle.

If a permanent record is required of the crack or other flaw indication, the following procedure should be followed, Figure 9.

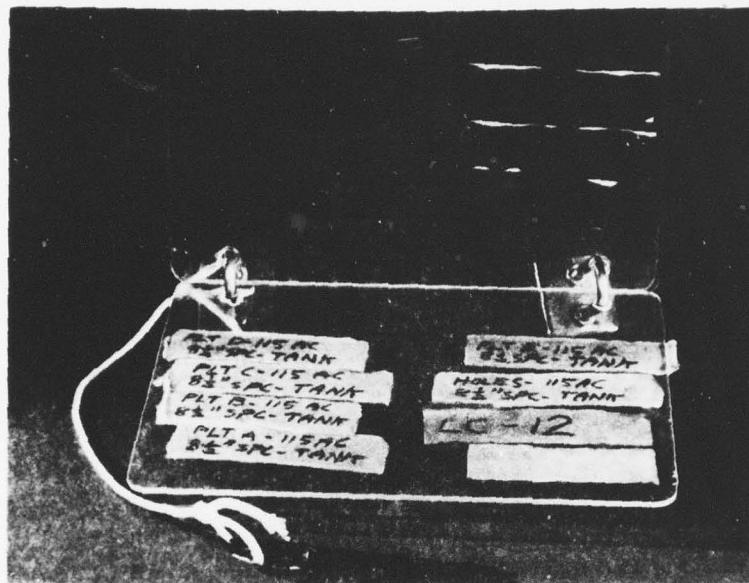


Figure 9. Acrylic Sheet Flaw Indication Recording Assembly

1. Press a strip of putty tape or duct seal onto the area.
2. Press or rub firmly while carefully holding in place.
3. Remove strip and place on an acrylic sheet.
4. Mark the rear, masking tape covered side of the tape with grease pencil to identify physical location of crack or flaw.

Where required, an ultraviolet light is used by the diver to make it easier to see the crack or flaw indication (both types of magnetic particles used were fluorescent).

Magnetic Paint

The magnetic paint was brushed onto the inspection area. If a crack or detectable flaw was present, the magnetic flux created caused magnetic flakes in the area to stand on end versus laying flat. This resulted in a noticeable line of contrasting color (grey-black).

TEST RESULTS

A summary and comparison of the relative effectiveness of the various tested magnets and magnetic particle mixtures are presented in Figure 10. As shown, the electromagnets are much more effective than the permanent magnets. Alternating current reportedly provides greater mobility of the

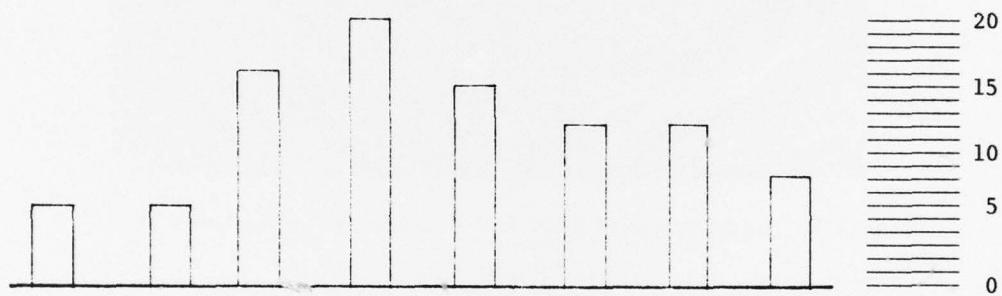
magnetic particles and may account for the higher success rate of the 115-VAC probe as compared to the DC probe.

A more complete tabulation of results is presented in Table 1.

An added advantage of the 115-VAC contour probe was that a larger area could be covered due to wider pole spread and the arms could be adjusted to match plate contour or laps.

A definite disadvantage was that the fluctuating 60-cycle current resulted in peaking and collapsing magnetic fields which in turn resulted in much less magnetic holding force. The 115-VAC probe would not hang on a vertical steel plate or below a horizontal steel plate without falling.

As shown in Figure 10, magnetic rubber was most effective in locating cracks with the two fluorescent particle-water mixtures falling a close second. A disadvantage of the magnetic rubber is the time required for use. It must remain in place 30 minutes or longer. It does provide an excellent permanent record of detected flaws. The fluorescent magnetic particles were very effective and had the advantages of allowing the diver to cover a larger area in much less time. The magnetic paint was not very effective and was difficult to make adhere even on freshly sanded steel plate.



1"	1½"	12	115	M	M	U	M
M	M	VDC	VAC	A	I	W	A
A	A	M	M	G.	G.	L	P
G	G	A	A	R	L	O	A
N	N	G	G	U	U	W	I
E	E	N	N	B	B	W	N
T	T	E	E	B	10		T
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Note: Only data for the following magnet pole spacings were used:

1" dia. perm.	--	4"
1½" dia. perm.	--	4"
12 VDC	--	4½"
115 VAC	--	6"

Figure 10. Flaw Detection Success Rate
(Total number of plates where flaws successfully detected)

TABLE 1
FLAW DETECTION SUCCESS
(X = FLAW DETECTED)

Magnetic Particle Media	Magnet Type	Magnet Pole Spacing	A	B	C	D	E	Test Plate 1/32" Hole*
Magnetic Rubber	1" dia. permanent	4"			X		X	
Magnetic Rubber	1½" dia. permanent	4"			X		X	
Magnetic Rubber	12 VDC	4½"	X	X		X	X	X
Magnetic Rubber	115 VAC	6"	X	X	X	X	X	X
Magnetic Rubber	115 VAC	8½"	X	X	X	X	X	X
MG-10	1" dia. permanent	4"					.010	only
MG-10	1½" dia. permanent	4"					X	
MG-10	1½" dia. permanent	6"					.010	
MG-10	12 VDC	4½"	X		X	X	X	X
MG-10	115 VAC	6"		X	X	X	X	X
MG-10	115 VAC	8½"		X	X	X	X	X
UW-1	1" dia. permanent	4"					X	
UW-1	1½" dia. permanent	4"					X	
UW-1	12 VDC	4½"	X			X	X	X
UW-1	115 VAC	6"	X	X	X	X	X	X
UW-1	115 VAC	8½"	X	X	X	X	X	X
Magnetic Paint	1" dia. permanent	4"					.015	
Magnetic Paint	1" dia. permanent	4"					.020	only
Magnetic Paint	12 VDC	4½"					X	
Magnetic Paint	115 VAC	6"	X				X	X
Magnetic Paint	115 VAC	8½"	X				X	X

*NOTE: Only the hole which was one-sixteenth inch below the surface was reliably detected by any method.

The putty tape and duct seal tapes both provided excellent permanent records of flaws while using the fluorescent magnetic particles. They adhered well to the clear acrylic sheets and provided a permanent record that was easy to read on the surface.

Both the stainless steel plate and .010-inch brass shim stock were effective in holding the magnetic rubber pouches in place.

The electrical connector on the mercury vapor-ultraviolet light failed prior to underwater testing, possibly due to operator error. A replacement connector has been ordered and the light will be tested in conjunction with the fluorescent magnetic particles in the near future.

CONCLUSIONS AND RECOMMENDATIONS

Only the electromagnets proved to be effective. The 12-VDC probe had greater holding power but the poles are fixed and this would restrict its use on contoured or lapped plate. The 115-VAC probe was most effective for flaw detection and had the advantage of adjustable pole pieces in terms of both width and angle. It lacked holding power to hang in place.

The magnetic rubber appears most effective if very accurate records are required of small width cracks. It had the disadvantage of being slow to use. The magnetic paint did not appear effective.

The mercury vapor-ultraviolet light did not appear to be required in clear water with adequate light but may be necessary in dark murkey water.

A diver may have problems trying to move with and use the combination of a light, magnetic probe, magnetic particle mixtures and the acrylic sheets. Some way of better combining or storing the equipment appears necessary.

Harbor and sea tests inspecting actual ship hulls and offshore platforms are clearly needed and are planned for the near future.

ULTRASONIC TESTING

There are two basic modes of UT: thickness gaging and flaw detection. Preliminary information revealed that underwater thickness gaging is done somewhat routinely, but that flaw detection was not. The authors were lucky enough, in the beginning of the work in underwater UT, to witness several thickness gaging jobs being performed, and they helped identify areas in which R&D would be fruitful. What follows is a description of the practices we observed and alternatives we developed.

Dual element contact transducers appeared to be the favorite choice for gaging sheet steel. Although this type of transducer is indeed an excellent choice for gaging new steel sheets it has several disadvantages when used on steel in the marine environment. For example, since the transducer must make intimate contact with the steel, it is clear that the minimum thickness in a corroded area will not be read if the transducer is bigger than the corrosion pits. Misleadingly large values will be recorded routinely. Also, since these transducers are typically about the size of a jelly bean, the diver's hand may have a tendency to cramp between the thumb and forefinger if he uses one very long. Finally, on well pitted steel you can get whatever thickness you want by moving the transducer around a little bit. In many cases it would be just as informative to receive a list of random numbers instead of the results of an ultrasonic gaging of corroded steel.

The authors also found that the diver is often supplied with a waterproofed thickness gaging instrument. In addition to the problems presented above, this practice requires the diver to use both hands, his eyes and his mind to conduct a survey. He may even have to adjust gain knobs while wearing thick gloves. This may be alright on easy jobs, but it is difficult, if not dangerous, to conduct a survey this way under a large ship where the diver needs his full concentration just to keep from getting lost.

To overcome these obstacles to objective and credible thickness gaging the authors approached the problem from a different point of view. In place of the contact transducer style, a focused immersion transducer is used. This transducer is recessed in a housing in such a fashion that its focal point is just below the steel's average surface, as shown in Figure 11. It can easily "look" into pits and therefore gages thickness at any location. A housing was necessary, both to waterproof the cable-to-transducer connection and to provide the proper stand-off for the transducer. This housing was made amply large, like a beer can, to keep the diver from cramping. This same housing also converts readily to an angle beam housing for flaw detection.

Finally, in order to get around the problem of the natural thickness variations on corroded steel, the ultrasonic instrument was tied into a small computer that rapidly samples thicknesses and, for each basic location, accumulates one hundred individual readings. It then finds the average, standard deviation, maximum and minimum of these one hundred data. This information (along with a location identifier entered by the topside operator) is printed out and stored on magnetic tape. Since the computer samples thickness extremely quickly and can reject much of the noise it receives, virtually no skill is required to manipulate the transducer. The diver does not have to find and hold a stable reading long enough for the topside operator to record it; instead, he merely rubs the housing around for about five seconds while the computer snatches readings. A flow chart showing the basic computer program is shown in Figure 12. Beyond what is shown on that flow chart, the computer actually does a considerable amount of filtering to eliminate electrical transients. It also prints out an index of the quality of the readings which usually relates to unbonded areas of the paint system.

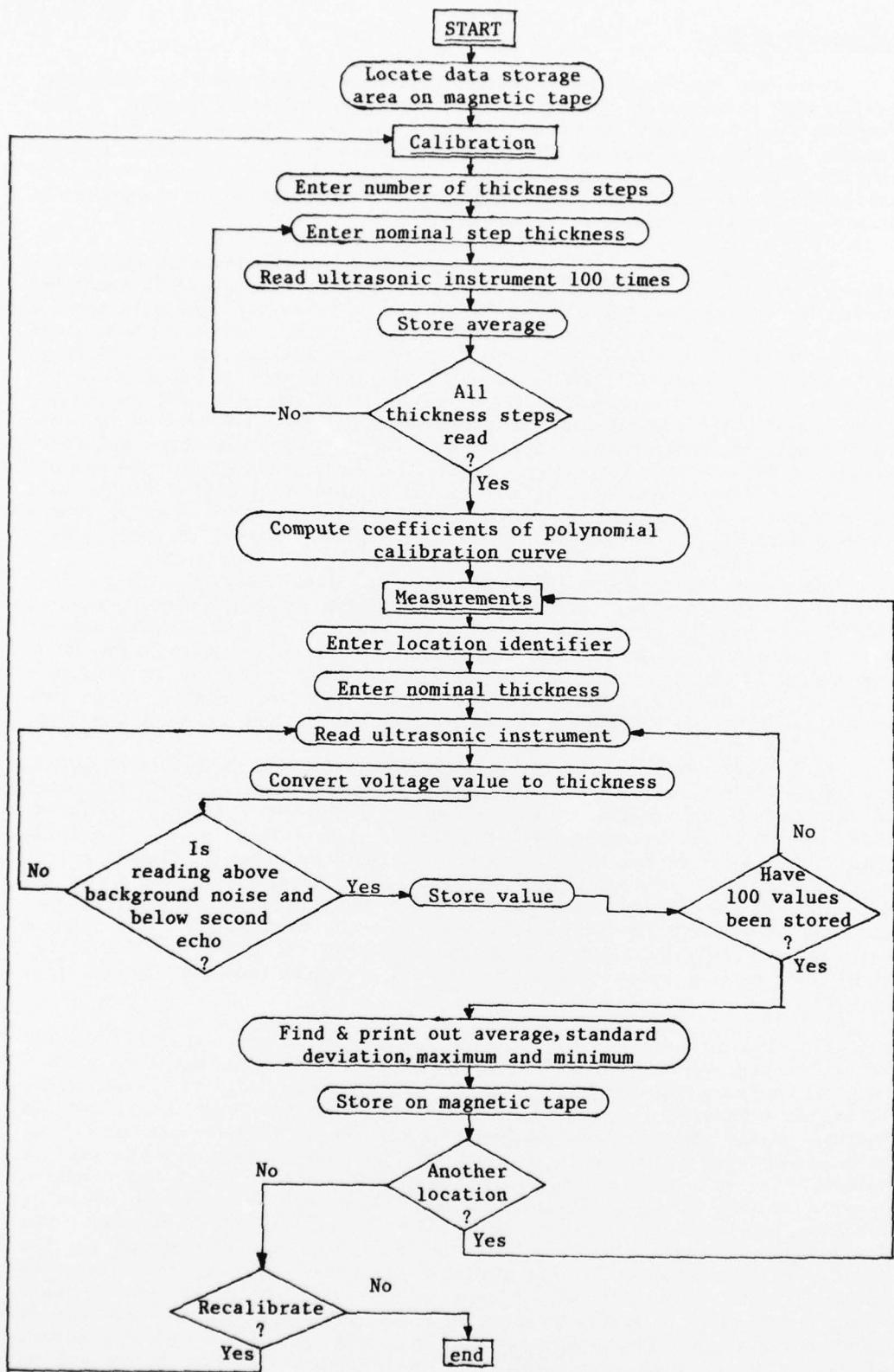


Figure 12. Simplified Computer Flow Chart for Thickness Gaging

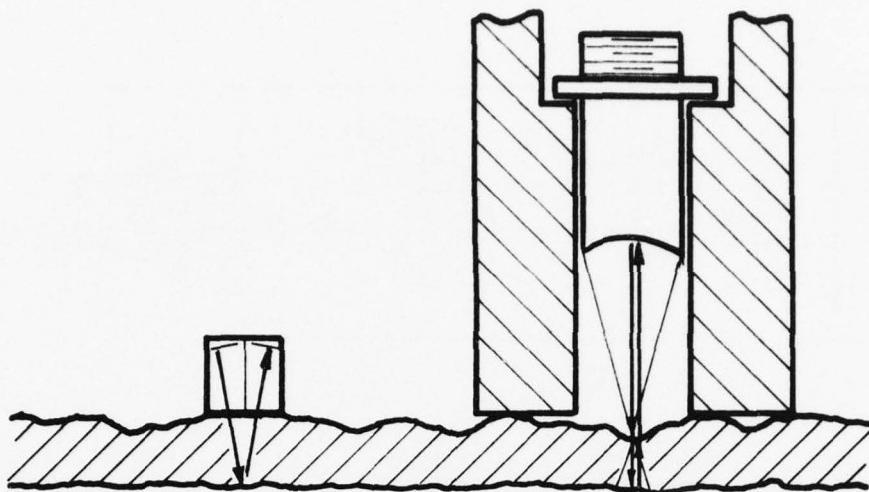
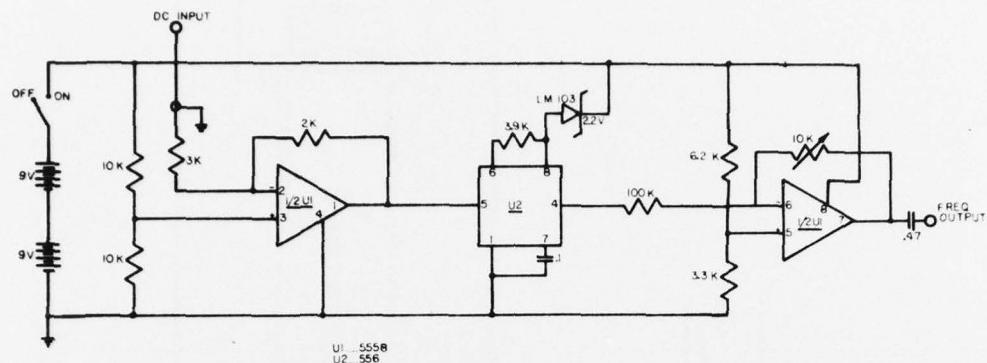


Figure 11. Dual Element Contact Transducer (Right) and Single Element Focused Immersion Transducer (Left)

During a recent operation at NCSC a portion of the hull of a 107-foot yard crane was gaged at each point on a 4" x 3" grid established with hogging lines. Using divers with absolutely no previous experience in ultrasonics, 142 readings were acquired in just under three hours of bottom time - about 1.3 minutes per reading as an overall figure. Several areas of significant corrosion were identified, although no pitting was visible from the exterior of the hull, and some of the thinned areas were inaccessible from inside the ship. This information will be used in the overhaul planning process which is now in progress.

Flaw detection is far more demanding than thickness gaging because it requires skill in transducer manipulation and in interpreting the signals. When flaw detection is done above water, the operator simultaneously moves the transducer around and looks at the cathode ray tube (CRT) to see if any spikes, or pips, come up. If they do, he carefully moves the transducer around until the spike is "peaked up," and then reads its location and amplitude. Unfortunately, the diver usually does not have a CRT display to give him feedback about where to move the transducer, and trying to get the information to him verbally has proved almost impossible. To overcome this, we have developed an audible tone generator (Figure 13) which gives the diver a whistling tone whose pitch varies according to the flaw signal's strength. This feedback allows him to find and "peak up" signals while a topside operator notes the location and amplitude of the signal. The process has only begun at this point since it is important to find where in the weld the flaw is. It may turn out to be nothing more than the weld bead's irregular surface or a root gap, neither of which are as threatening as an underbead crack or fatigue crack in the heat affected zone. At present the topside operator reports the flaw position, relative to the transducer, and the diver measures from the transducer to the flaw. He then reports where, relative to the weld centerline, the flaw is. This whole latter process could be automated with the present computer tie-in we have (Figure 14) but considerable work will be required before it will be ready for use by a diver with little or no ultrasonic training. In the meanwhile, the audible feedback system makes it possible to do coarse weld inspections, leaving the detailed work to a magnetic particle inspection of the suspect area.



**Input Level
Conditioning**

**Voltage
Controlled
Oscillator**

**Volume Control
Control**

Figure 13. Audible Tone Generator Circuit

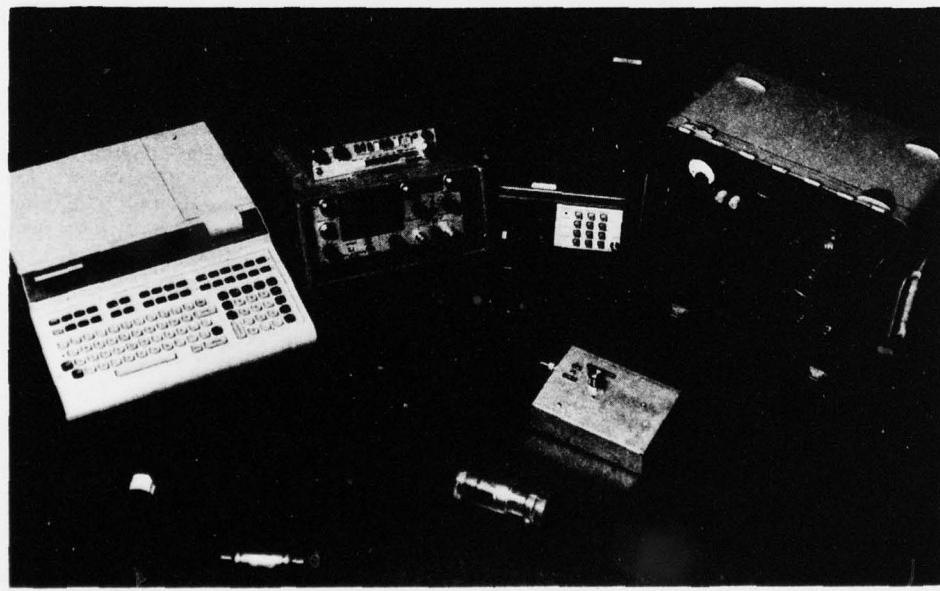


Figure 14. Underwater Ultrasonic Inspection System

STEREOPHOTOGRAPHY

Underwater photography is a well established technique. Inspection reports almost always abound in color prints taken at various locations around the structure. But all too often, even though the prints are aesthetically pleasing, very little useful engineering information can be derived from them. Part of the reason often has to do with focus and lighting, but just as often, the features of interest, such as corrosion pits, fouling, paint blisters and weld cracks, are just too small to be seen clearly. This condition, as well as focus and lighting, can be cured by supplementing the overall views with close-up photography. Commonly used for close-up work are extension tubes which are commercially available in a range of sizes.

In the Navy environment we are plagued by the turbid waters common to all shipyards. Thus, in addition to close-up tubes we found it necessary to provide a clearwater box between the camera and the subject. This box (Figure 15) was built to be pressed up to the ship's hull, eliminating all but one-half inch of dirty water from the camera's "line of sight." With this device, focus and aperture can be preset, resulting in consistently high quality photographs regardless of the diver's skill. The clearwater box was constructed in such a way that the camera, an ordinary Nikonos, can be moved about an inch sideways. If two exposures of the same area are made with this motion between them, a stereo pair results.

Experience with the stereo apparatus has demonstrated its potential for supplying engineering information. Elevations can be measured with an accuracy of about one-sixty-fourth of an inch, thus permitting the severity of corrosion pitting to be quantified quite accurately. Also, the third dimension is a great aid in interpreting the photographs, since such features as unpopped paint blisters, weld beads and lap joints, are readily identifiable, even though on a single photograph they may easily be mistaken for simple discoloration. Figures 16 and 17 are reproduced from color stereo pairs. Even in black and white they reveal a surprising amount of information when viewed stereoscopically.

SUMMARY

Research and development in underwater nondestructive testing has resulted in advances in magnetic particle, ultrasonic and stereophotographic hardware. In each area the hardware permits a diver with minimal NDT skills to perform objective surveys that output hardcopy results for evaluation by topside personnel. These results can be a valuable management tool for planning maintenance and repairs and can be used to substantiate controversial decisions.

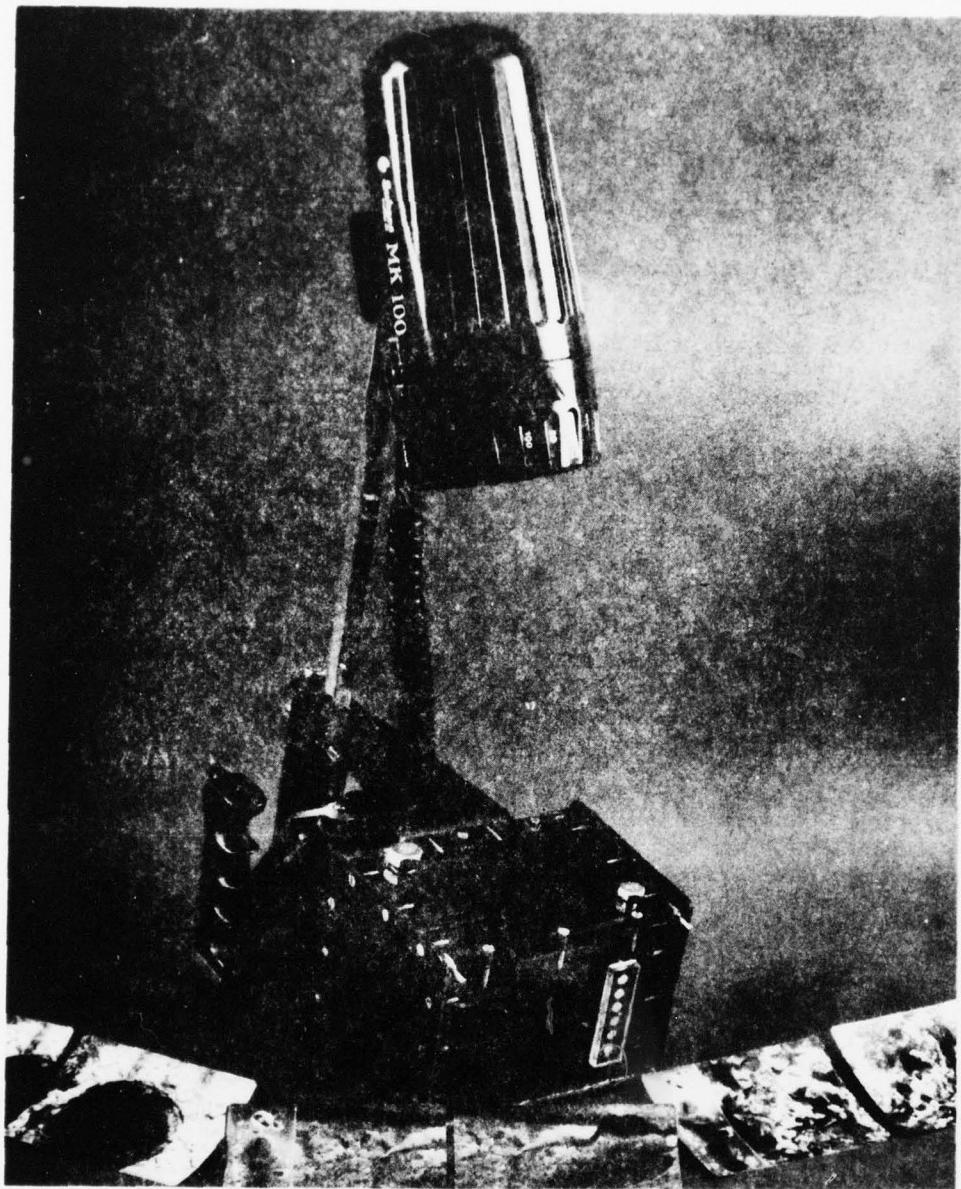


Figure 15. Stereophotography Assembly

Figure 16. Paint Failure

This example shows a general failure of the outer paint layer, with relatively little disturbance of the underlying layer. There are, however, small blisters (1/16" - 1/8" diameter) visible in the undercoat. A weld bead runs diagonally across the upper right corner of the stereo area.

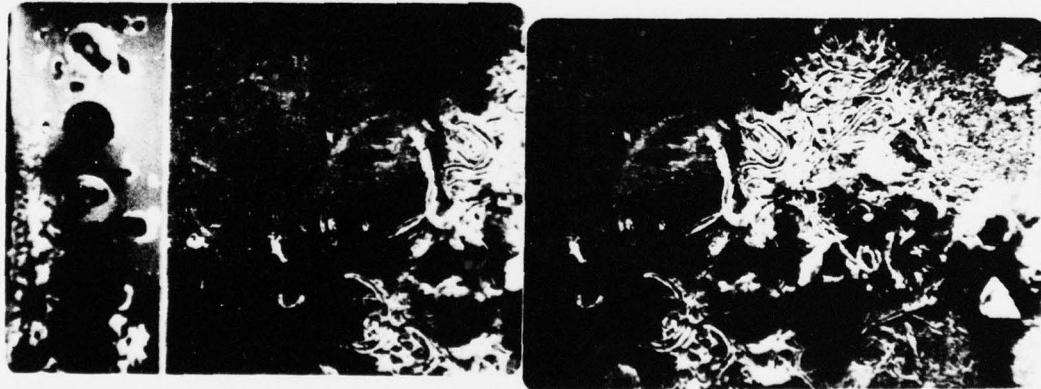
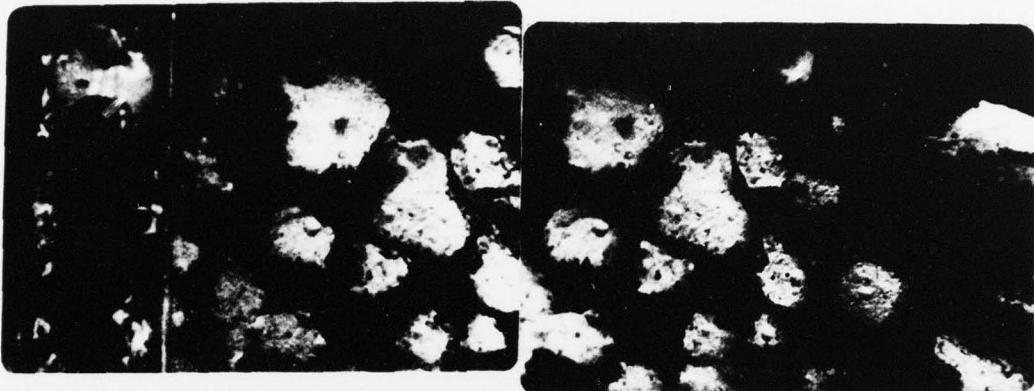


Figure 17. Unpopped Paint Blister

In the center of the stereo area there is a paint blister, as yet unpopped. There is a heavy algae slime to the left of the blister, and vestiges of a tubeworm colony to the right. Also, a small stalk of brown algae can be seen about one-half inch right of the blister.